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Wireless transceiver bit error rate and capacity improvement using advanced decoding techniques

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Article Info

ABSTRACT

This paper considers advanced techniques for multiple-input multiple-output (MIMO) detection and decoding techniques to improve bit error rate (BER) and channel capacity. These are requirements for sixth generation (6G) (the next generation) access networks. A parallel decoding and detection scheme and a soft bit decoding scheme are implemented meregely to boost the overall performance of MIMO communication systems. The proposed new system is called the advanced system which comprises the two mentioned advanced techniques of decoding. For simplicity, these advanced techniques are employed and developed using two antennas at both ends, transmitter, and receiver. Then it is compared with the other different techniques which are spatial multiplexing SM–sequential decoding zero forcing-interference cancelation (ZF-IC) technique and SM–parallel decoding technique. We show that the advanced system outperforms the other two mentioned systems by achieving ultra-reliability and a high capacity simultaneously without employing space time coding and error control coding techniques. Additionally, better BER performance is achieved with less resolution and the quantization error reduced with an increasing the resolution. The new advanced system is simulated and evaluated with three terms, channel capacity, BER, and quantization error.

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1. INTRODUCTION

Wireless communication is one of the most escalated fields due to the excess demand in sophisticated communication services. The fifth generation-new radio (5G–NR) networks are anticipated to expand channel capacity and boost the reliability which is highly spectrally efficient wirelesses communications [1]–[5]. These requirements can be accomplished using multuple antennas for the transmitter and receiver. The specialization of multiple-input multiple-output (MIMO) technology is which it exhibits benefits to improve the data rate and the quality of transmission without reqiring the additional bandwidth, that is a master challenge in wireless communications. One of the biggest challenges in MIMO communication systems is the trade-off between higher data rate and lower bit error probability. Thus, error concealment technique will be engaged in the MIMO communication system to increase the reduction of the bit error rate (BER). Error concealment technique depends on three parameters. First, statistical description obtains about the source encoder and uses as a priori knowledge, second and third are the hard bit itself with its reliability, respectively. Reliability means the estimated probability of bit-error, the combination of

reliability with the received hard bit called soft bit. Maximum a posteriori probability (MAP) estimator is selected to carry out the estimation of symbols [6].

In this paper, the two advanced techniques are proposed and combined which are error concealment technique and a parallel decoding and detection algorithm for MIMO communications systems. Our new system significantly reduces the bit error probability, without using the conventional techniques of error control codes, and efficiently increases the data rate at the same time. This paper is organized as shown in. Section 2 describes the principle of error concealment scheme where the parallel decoding and detection technique is justified in section 3. The combination of these two advanced proposed techniques is introduced with its theoretical analysis in section 4. The discussion of the obtained results is introduced in section 5 and it concludes in section 6.

2.   ERROR CONCEALMENT TECHNIQUE

The principle of error concealment technique is to reduce the bit error probability and Figure 1 demonstrates the principle of this technique. The source parameters are quantized and encoded to bit combinations called codeword. An a priori knowledge can be obtained from the output of the quantizer, source encoder, and by computing how often each codeword occurs at the output. This statistical explanation about the source encoder stored at the receiver to combine with transition probability to figure out the a posteriori probability [7]–[10]. Map estimator was selected to perform the estimation of transmitted symbol.
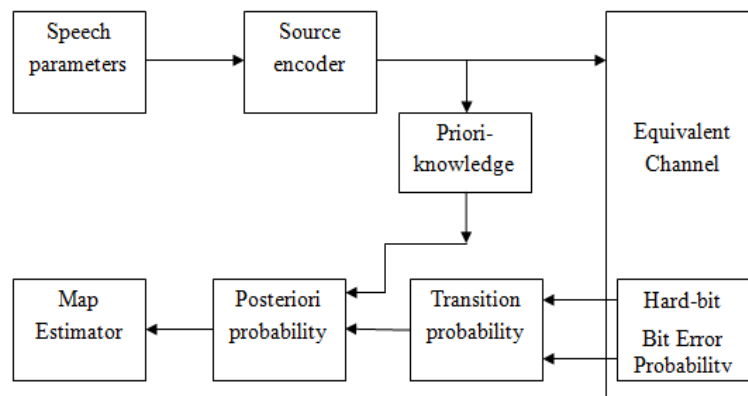

Figure 1. Error concealment concept

3.   PARALLEL DECODING AND DETECTION TECHNIQUE FOR MIMO SYSTEMS

This section discusses the parallel decoding technique for MIMO communication systems [11]. The major of this technique is to achieve both a high data rate and a less bit error probability concurrently. This achievement is accomplished by enabling the receiver to decode and detect all the received modulated symbols cocurrently and independently in which they are transmitted at single symbol period by employing spatial multiplexing technique at the transmitter such as vertical-bell laboratories layered space-time (V-BLAST), horizontal-BLAST (H-BLAST), and diagonally-BLAST (D-BLAST) [1], [12].

On the other side, the proposed technique is used to decode each one of these received symbols by pre-multiplying the overall received signal by a specific matrix which is defined by the null space of the partial channel matrix that is associated with the remaining received matrix. Thus, each estimated formula of received signal is dependent only on the corresponding received symbol. Therefore; the requirements are achieved: a higher data rate and a better transmission reliability.

4.   COMBINATION OF ADVANCED TECHNIQUES

This section mixes these two proposed techniques, error concealment technique and parallel decoding and detection technique for MIMO communication systems. For simplicity, the rest of this paper focuses on using two antennas at both ends, transmitter and receiver. Figure 2 demonstrates a 2×2 MIMO–parallel decoding system, aided by error concealment [13]–[15]. As mentioned, the codec parameter $Q[v_0] = v_0$ is quantized according to $v_0 \in QT$ with $v_0 \in QT$ where QT denotes the quantization table with index $l \in \{0,1, \dots, 2^M - 1\}$. By bit mapping (BM), a bit combination x_0 is represented as shown in:

$$x_0 = (x_0(0), x_0(1), \dots, x_0(m), \dots, x_0(M-1)) \tag{1}$$

Where M represent the number of bits for each quantized symbol, the quantized symbols are represented by bipolar, that means $x(m) \in \{-1, +1\}$ or it can be said $v_0 = v_0^{(l)}$ as well as $x_0 = x_0^{(l)}$ [6], [15].
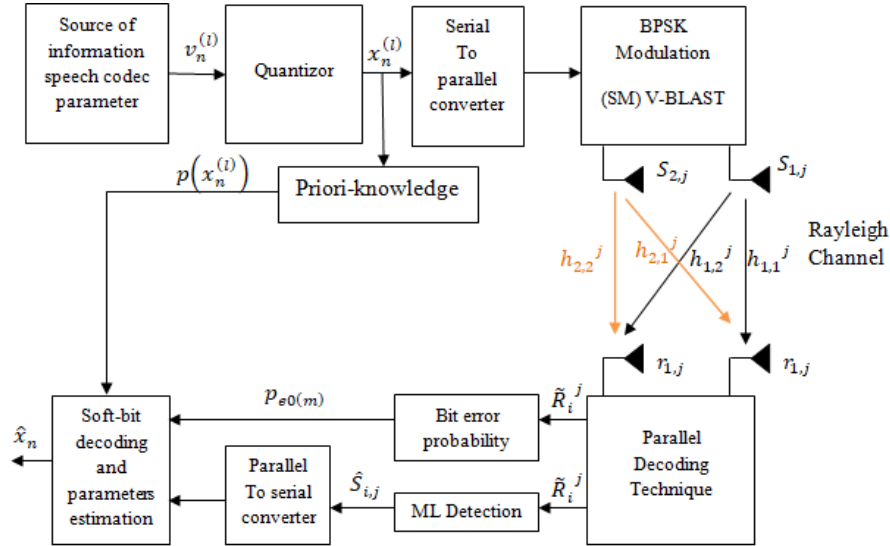

Figure 2. The proposed system

Statistical description of the output of source encoder is modeled as 0th order Markov process, thus 2^M probabilities $p(x_n^{(l)})$ with $l \in \{0, 1, \dots, 2^M - 1\}$), these probabilities are stored at the receiver (softbit decoder). The output binary data of the source encoder are moved to serial-in/parallel-out converter to get ready for transmission using MIMO communication technique. These bits combinations $x_n^{(l)}$ is modulated using simple type of digital modulation which is a binary phase-shift keying (BPSK) then mapped to a unique transmit antenna using a MIMO communication technique. For the sake of simplicity, consider two transmit and receive antennas are used $N_t = N_r = 2$, and MIMO system is shown in Figure 2. The transmitter transmits two different modulated symbols at single symbol duration using a V-BLAST technique [16]–[18]. Accordingly, the transmitted signal matrix S is:

$$S = \begin{bmatrix} S_{1,1} & S_{3,2} \dots S_{(1-i),j} \\ S_{2,1} & S_{4,2} \cdots \quad S_{i,j} \end{bmatrix} \tag{2}$$

Where i denotes the modulated symbol index and j denotes the symbol period index. It is remarkable to say that the total required number of symbol periods is half the total number of modulated symbols that are transmitted. This implies the speed of transmission is twice of a SISO system. The channel matrix H are as shown in.

$$H = \begin{bmatrix} h_{1,1}^{1} & h_{1,2}^{1} & h_{1,1}^{2} & h_{1,2}^{2} & \dots & h_{1,1}^{j} & h_{1,2}^{j} \\ h_{2,1}^{1} & h_{2,2}^{1} & h_{2,1}^{2} & h_{2,2}^{2} & \cdots & h_{2,1}^{j} & h_{2,2}^{j} \end{bmatrix} \tag{3}$$

With the expression of $h_{p,q}^{j}$, p and q are the indices that indicate the number of receiving and transmitting antenna, respectively. Using the proposed detection and decoding algorithm, each two received symbols is detected, decoded concurrently, and independently. Additionally, there are two extracted replicas for each transmitted symbol. Under assumption of Rayleigh channel environments, the channel matrix is decomposed as shown in:

$$H = \begin{bmatrix} H_1^{1} & H_2^{1} & H_1^{2} & H_2^{2} & \dots H_1^{j} & H_2^{j} \end{bmatrix}, where \ H_q^{j} = \begin{bmatrix} h_{1,q}^{j} \\ h_{2,q}^{j} \end{bmatrix} \tag{4}$$

For simplicity, we describe the mathematic expressions of decoding symbols at the first symbol period only. The received signal $r^1 = r$ as shown in Figure 2 is:

$$r = r_1 + r_2 \tag{5}$$

Where $r_1 = \sqrt{\rho}\left(h_{1,1}{}^1 S_{1,1} + h_{1,2}{}^1 S_{2,1}\right) + Z_1$, and $r_2 = \sqrt{\rho}\left(h_{2,1}{}^1 S_{1,1} + h_{2,2}{}^1 S_{2,1}\right) + Z_2$. In terms of vectors and matrices form, the multi–received signal matrix is:

$$R = \sqrt{\rho}HS + Z \tag{6}$$

Decoding each received symbol ($S_{1,1}$ and $S_{2,1}$) that are transmitted at the first symbol period, is achieved by pre-multiplying the received signal matrix by A_i matrix.

$$\tilde{R}_i \triangleq A_i R \tag{7}$$

Where $A_{i(1\times 2)} = nullspace\left[H_{c-c_i}{}^1\right] = [a_{1,1} \quad a_{1,2}]$ while $H_{c-c_i}{}^1$ is represented the channel elements that caused an interference in a decoded processing of $S_{i,1}$ symbol. Therefore, the estimated received matrix $\tilde{R}_i$ to decode $S_{i,1}$ symbol can be rewritten as [19]–[22].

$$\tilde{R}_i = \sqrt{\rho}A_i H_i{}^1 S_{i,1} + A_i Z = \sqrt{\rho}H_i{}^{(eff)-1}S_{i,1} + \bar{Z}_t \tag{8}$$

Where $H_i{}^{(eff)-1}$ states to the effective channel matrix that is accompanied with transmitting $S_{i,1}$ symbol, which can be represented as:

$$H_i{}^{(eff)-1} = [a_{1,1} \quad a_{1,2}] \begin{bmatrix} h_{1,i}{}^1 \\ h_{2,i}{}^1 \end{bmatrix} \tag{9}$$

The noise term is $\bar{Z}_t = A_i Z$. As shown in (8) and (9), there are two replicas $\left(\sqrt{\rho}a_{1,1}h_{1,i}{}^1, \sqrt{\rho}a_{1,2}h_{2,i}{}^1\right)$ of $S_{i,1}$ symbol that are received by the first and second receive antennas, respectively. We can apply ML decoding to (8) to get the estimated $\hat{S}_{i,1}$ symbol as shown in.

$$\hat{S}_{i,1} = \arg\min_{\{S_{i,1}\}} \left\{ \left\| \tilde{R}_i - \sqrt{\rho}H_i{}^{(eff)-1}S_{i,1} \right\|_F^2 \right\} \tag{10}$$

Noteworthy, the detection and decoding of two received symbols are accomplished independently and cocurrently. This implies that the signal processing speed of thus data rate at the receiver is doubled when compared to an identical 2×2 MIMO system, which uses serial detection that is used in methods such as zero forcing-interference cancelation (ZF-IC) and linear minimum mean square error-interference cancellation (LMMSE-IC) [22]. Also, contrary to some serial detection methods that use interference cancellation, with the new model, the error will not propagate to following symbols if the present symbol detected with an error. Furthermore, this system provides cocurrently both of spatial diversity and spatial multiplexing techniques. Therefore; the proposed 2×2 MIMO system enhances the reliability with an increasing the channel capacity cocurrently in addition to enhance the reliability more using error concealment decoding technique. With rank of the channel matrix equal to two (r = 2) the channel capacity of 2×2 MIMO system is modeled with of (11):

$$C_{(2\times 2)MIMO} = \sum_{i=1}^{2} \log_2\left(1 + \frac{\rho}{2}\lambda_i\right) \tag{11}$$

Therefore, the capacity of this system is twice as the channel capacity of both single-input-single-output (SISO) and a 2×2 MIMO using Alamouti code, while it is the same as the 2×2 MIMO capacity using standard spatial multiplexing. The diversity order of this 2×2 MIMO communication system is influenced by the number of the receiver and transmitter antennas difference, because the number of signal replicas is twice the rows number of pre-multiplying matrix. Accordingly, the diversity order N_d specifically is:

$$N_d = 2 * (N_r - N_t + 1) = 2 \tag{12}$$

The V-BLAST 2×2 MIMO–error concealment system when using the advanced parallel decoding and detection technique accomplishes both requirements of spatial diversity and spatial multiplexing

cocurrently. Hence, we recognize this decoding under hard-bit decoding (HD). Thereafter, we proposed an addition new technique to diminish the bit error probability more. With decoding processes, an additionally parameter is required to the received hard bit $\hat{x}_0$, this parameter is the estimated bit error probabilities of the received bit combination $\hat{x}_0$, and it can be found as shown in [18].

$$p_{e0} = p_{e0}(0), p_{e0}(1), \dots p_{e0}(m), \dots p_{e0}(M-1) \tag{13}$$

The channel is depicted with Figure 2 Rayleigh channel, with the instantaneous probability of bit-error and the factor of fading, probability of bit-error for the received bit can be computed as:

$$p_{e0(m)} = \frac{1}{1+exp|L_c.\tilde{x}_0(m)|} \tag{14}$$

With $L_c = 4\alpha.\frac{E_b}{N_0}$ and $\tilde{x}_0(m)$ represents the received real value [6]. Thus, for each received value $\tilde{x}_0(m)$ a probability of bit-error is assigned. The couple of information, received bit and estimated probability of bit-error is represent an error concealment. Transition probabilities are computed for an error concealment decoding as first step algorithm, i.e. $P(\hat{x}_0/x_0^{(l)}), l \in \{0, 1, \dots, 2^M - 1\}$. Transition probability means the probability of received symbol $\hat{x}_0$ given that $x_0^{(l)}$ is transmitted; transition probability can be computed as [20]:

$$P(\hat{x}_0(m)/x_0^{(l)}(m)) = \begin{cases} 1 - p_{e0}(m) \, if \, \hat{x}_0(m) = x_0^{(l)}(m) \\ p_{e0}(m) \, if \, \hat{x}_0(m) \neq x_0^{(l)}(m) \end{cases} \tag{15}$$

Thus, the transition probability for memoryless equivalent channel, as assumed in this paper, can be found as:

$$P(\hat{x}_0/x_0^{(l)}) = \prod_{m=0}^{M-1} P(\hat{x}_0(m)/x_0^{(l)}(m)) \tag{16}$$

Second step for decoding is to find the 2^M a posteriori probabilities $p(x_0^{(l)}/\hat{x}_0)$ with $l \in \{0, 1, \dots, 2^M - 1\}$ by combination the obtained parameter transition probabilities $P(\hat{x}_0/x_0^{(l)})$ with 0th order a priori knowledge, respectively. Using Bayes rule to give the posteriori probabilities which represent probabilities of any possibly transmitted bit combinations $x_0^{(l)}$ given that received one $\hat{x}_0$. Baye's rule shown in (17) [17], [23]:

$$p(x_0^{(l)}/\hat{x}_0) = C.p(\hat{x}_0/x_0^{(l)}).p(x_0^{(l)}) \tag{17}$$

With the normalization constant:

$$C = \frac{1}{\sum_{l=0}^{2^M-1} p(\hat{x}_0/x_0^{(l)}).p(x_0^{(l)})}$$

Finally, the maximum a posterior probability is selected to estimates the transmitted parameter. The posteriori probabilities are used to compute optimum values for transmitted symbols. MAP estimator is selected according to the following criterion [20], [24], [25].

$$v_0^{(MAP)} = v_0^{(v)} \, with \, v = \arg max_l \, p(x_0^{(l)}/\hat{x}_0)$$

5. SIMULATION RESULTS

This section describes the performance of a (2×2) MIMO–error concealment communication system using BPSK modulation with different value of a resolution. The performance is measured by plotting BER and channel capacity respect to the Eb/N0 ratio in dB using Matlab codes. Under assumption of the resolution M=2, Figure 3 demonstrates BER of a (2×2) MIMO–parallel decoding communication system with and without employing error concealment and compares with a 2×2 MIMO-spatial multiplexing that implements sequential decoding which can accomplish spatial multiplexing only.

The result indicates that the (2×2) MIMO–parallel decoding communication system significantly performs better than (2×2) MIMO–zero forcing interference cancellation due to the parallel decoding technique which reduces the BER, increases the speed signal processing, prevents error propagation, and

increases channel capacity. Using the other advance technique, which is error concealment, the BER is efficiently less than the other two systems due to exploiting the advanced concept of soft bit decoding which is advanced by [6]. Additionally, exploiting the reliability information in soft bit source decoding makes the soft decoding scheme overcomes the hard decoding scheme by approximately 5 dB at 10 dB of Eb/N0.
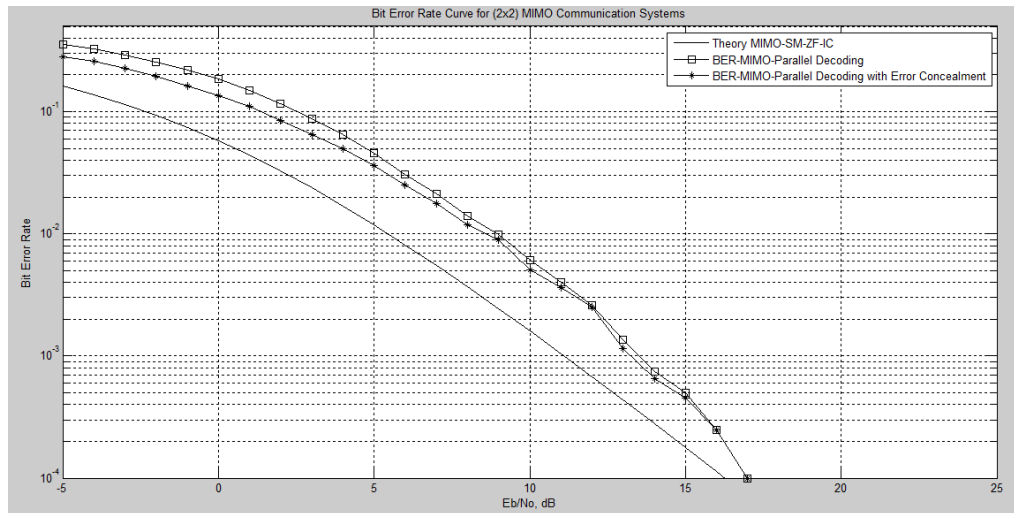

Figure 3. BER of (2×2) MIMO systems

While BER of the (2×2) MIMO–parallel decoding with error concealment depends on the value of resolution, Figure 4 shows BER with different value of the resolution. The result shows that there is a directional relation between the BER and the resolution. This implies that the BER increases with an increasing the value of the resolution. On the other word, the better BER is with less resolution, because of the statistical description is more accurate for the output of source encoder (quantizer) with less index.
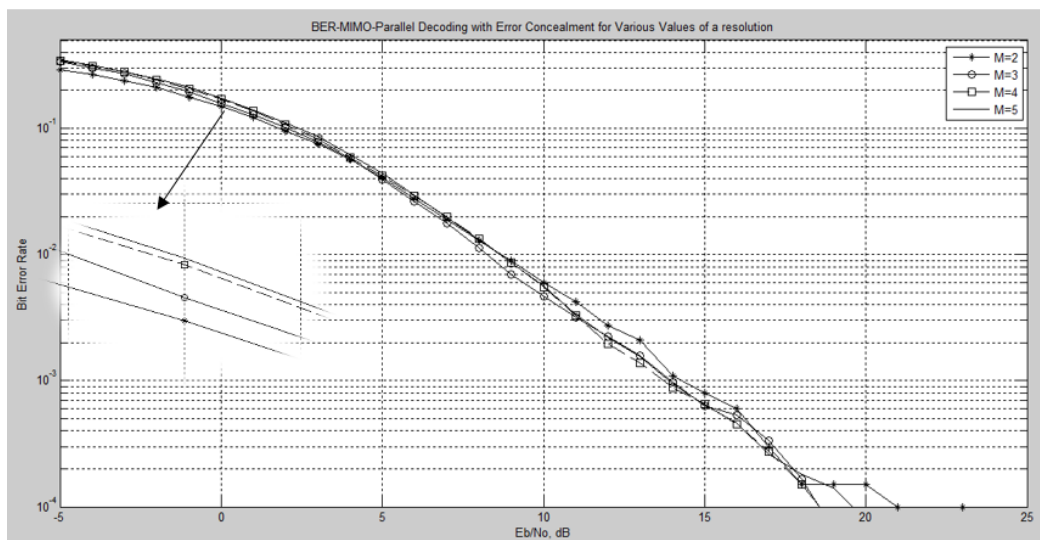
Figure 4. BER of the advanced system for various values of a resolution

The quantization error of the (2×2) MIMO–parallel decoding with error concealment system using resolution M=2 is shown in Figure 5. This figure shows the quantization error in three different values of the Eb/N0 ratio for using a resolution M=2. It is important to note that the quantization error decreases with an increasing the Eb/N0 ratio. On the other hand, increasing the resolution reduces the quantization error as shown in Figure 6. This figure shows various quantization error curves at Eb/N0 = 10 dB. The result shows the standard algorithm which is lest quantization error with the higher value of a resolution.
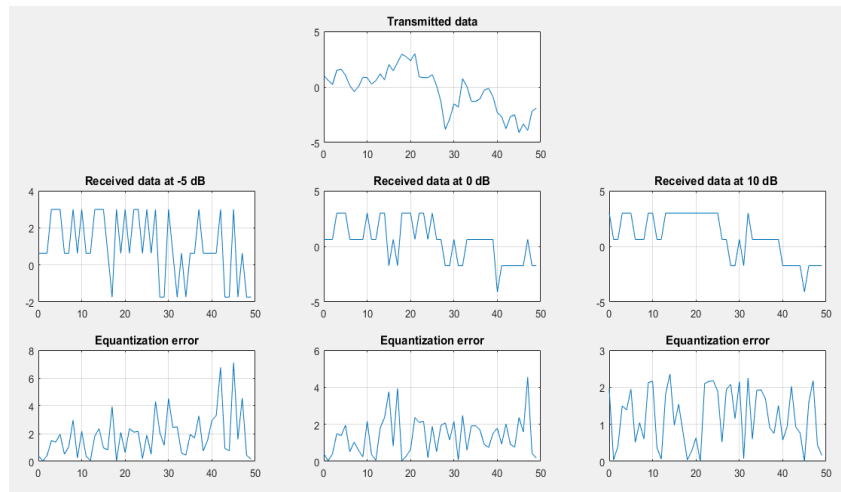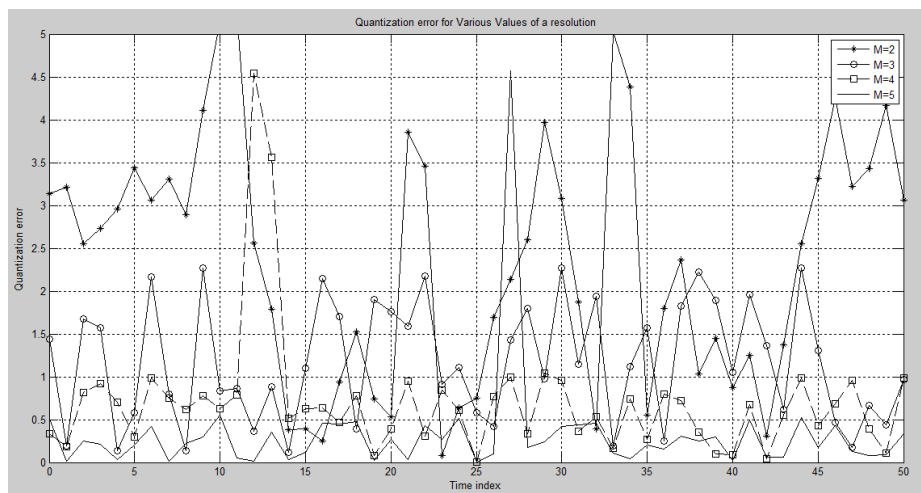
Figure 5. Quantization error

Figure 6. Quantization error for various value of resolution at $E_b/N_0 = 10\ dB$

In addition to the transmission reliability enhancement, there are the other advantages of the proposed advanced system which prevents error propagation, gets faster decoding, and detection process due to parallel scheme. Also, this parallel scheme increases the signal transmitting speed. This implies that the channel capacity is improved for a 2×2 MIMO system simultaneously with reliability enhancement as presented in Figure 7.
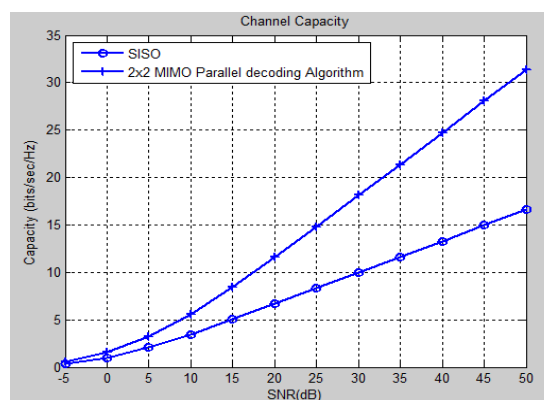
Figure 7. Channel capacity

The result shows that the (2×2) MIMO–parallel decoding with or without error concealment system significantly performs better channel capacity than SISO system which it is a twice. The above analysis and results show the system that implements a spatial multiplexing technology at the transmitter and the parallel decoding and detection technology with error concealment at the receiver advances both channel capacity and transmission reliability cocurrently, which cannot be accomplished by other similar algorithms. It is important to say that this advanced system can be generated for any number of transmit and receive antennas using any types of a digital modulation.

6. CONCLUSION

The very high channel capacity and ultra-transmission reliability are the requirements of the 5G- NR access networks. Thus, this paper is focused on the advanced techniques to enhance the overall performance of MIMO communication systems. A parallel decoding and detection scheme and a soft bit decoding are called the advanced techniques. In which, a soft bit decoding scheme is used for quantized input of source signal which is transmitted over Rayleigh channel distribution. This technique depends and exploiting the prior knowledge or explanation of the output of the source encoder to provide the greatest performance of the advanced system in terms of BER evaluation. The second technique, which is a parallel decoding and detection technique, achieves a better transmission reliability and a higher channel capacity simultaneously. Due to a parallel scheme, it is prevented error propagation that is common in sequential scheme, and it is increased the signal decoding and detection processes. It was shown that the advanced system outperforms the parallel hard decoding and detection scheme without concealment scheme and the sequential decoding and detection scheme. Also, as shown in the simulation results, the better BER performance is achieved with less resolution. However; the quantization error reduced with an increasing the resolution.

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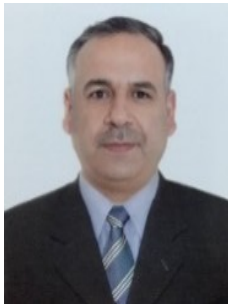
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